OUTSOURCING THE EXTREME ULTRAVIOLET EXPLORER (EUVE) MISSION FROM NASA GSFC TO THE UNIVERSITY OF CALIFORNIA, BERKELEY

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ABSTRACT

The NASA Extreme Ultraviolet Explorer (EUVE) satellite was launched on June 7, 1992. EUVE Project Management and Project Science responsibilities at the time of launch were located at the NASA Goddard Space Flight Center (GSFC) in Greenbelt, MD. Contracts were awarded to 1) Lockheed Martin Space Mission Systems and Services Corp. (LM), formerly Loral Aerosys, for the command and control of the spacecraft (S/C) bus and 2) to the University of California at Berkeley (UCB) for operation and management of the UCB-built EUV payload and science data processing. In April 1996, UCB and GSFC began the process of jointly "outsourcing" EUVE operations from GSFC to UCB, including the operation of the S/C bus, the role of GSFC Project Scientist, and ongoing Programmatic responsibility for the mission. The transition was successfully completed in March 1997. This paper provides details on the technical and programmatic structure of the mission at the time of the outsourcing, the procurement and technical processes undertaken to accomplish the handover, various challenges encountered along the way, and an enumeration of lessons learned.

INTRODUCTION

EUVE is the first astronomical satellite devoted exclusively to the study of celestial objects at the extreme ultraviolet (EUV) wavelengths, 60-760 Angstroms. This is because of the intrinsically faint nature of EUV sources, the high background level associated with the EUV geocoronal glow around the earth, technical difficulties in reflecting and detecting EUV radiation, and most importantly, the opacity of neutral hydrogen and helium in the interstellar medium (ISM) to EUV radiation. In the years before the EUVE mission, it became generally recognized that the ISM was distributed unevenly, as well as significantly ionized, making it more transparent to EUV radiation. Thus, NASA was motivated to conduct a systematic study of the heavens in the EUV band. The Program's primary mission was for UCB to perform the first all-sky survey in the EUV, followed by a three year Guest Observer program to conduct spectroscopic observations of select EUV sources. Accordingly, the payload consists of three Scanning Telescopes, one Deep Survey/Spectrometer, seven detectors, and associated electronics. The primary mission was successfully completed in early 1996 and EUVE is now in an extended mission phase. Significant contributions have been made by the mission to the understanding of the nature of stars, especially white dwarfs and cool star chromospheres and coronae, the state of the ISM, the dynamics of interacting stellar binary systems, and the mechanisms for high energy production in the centers of some galaxies. Overviews of the mission and the scientific results are available in the literature.[1,2]

BACKGROUND

Project management for the EUVE mission originally began at the NASA Jet Propulsion Laboratory but was moved to GSFC by NASA Headquarters (HQ) in the mid-1980's. In 1991 HQ also reversed an earlier programmatic decision that would have made the UCB-built EUVE payload the first in a series of experiments to be mated to a Shuttle-serviceable Explorer Platform (EP) over a ten year period. Since considerable design work had already been accomplished, it was decided to maintain the platform/payload distinction in the satellite design and not preclude the possibility of Shuttle servicing should the need arise. The final operations concept thus became a Shuttle-compatible, but Delta-launched, single payload satellite. Data flow is accomplished from the EP/EUVE spacecraft through the NASA Tracking and Data Relay Satellite System (TDRSS) to GSFC. The data was originally provided to both an EP (S/C bus) control center at GSFC, and to a UCB EUVE Science Operations Center (ESOC) at Berkeley for command and control of the EUVE instruments. The spacecraft design chosen was the Fairchild Multimission Modular Spacecraft (MMS) which was a highly successful attempt in the 1970's and 1980's to contain costs and reduce risks through the use of a common spacecraft bus. Other NASA missions which have flown the MMS design include the Solar Maximum Mission (SMM), the Upper Atmosphere Research Satellite (UARS) and the Compton Gamma Ray Observatory (CGRO).

MSOCC and Other GSFC Institutional Resources

As a reflection of the multi-purpose spacecraft design, a multi-use ground system called the Multi-Satellite Operations Control Center (MSOCC) was developed at GSFC. The missions supported by MSOCC are all in low earth orbits, so much of the time they are out of contact with the ground. MSOCC was built to take advantage of this by providing interchangeable strings of equipment which could be reconfigured to support whichever satellite pass required them. Based upon the technology of the time, a number of Perkin-Elmer large-framed minicomputers and associated disk packs and 9-track vacuum tape recorders were therefore configured by a team of computer operators to support a 20-30 minute EUVE spacecraft pass every orbit. Decommutated data was remotely formatted and displayed in a EUVE Mission Operations Room (MOR), which along with a second Mission Analysis Room (MAR), comprised the day-to-day work area for the EP Flight Operations Team (FOT). A nearby room housed the Command Management System (CMS), a shared IBM mainframe and associated DEC MicroVAX system. The CMS was used to provide command load generation functionality for several missions and to facilitate the interface to the shared TDRSS Space Network scheduling device, the User Planning System (UPS). Payload and platform data was also forwarded by the NASA Communications System (NASCOM) to the GSFC Sensor Data Processing Facility (SDPF) where level-0 processing and raw data archive of the science data was accomplished on satellite tape recorder dumps. A near real-time feed of non-dump (real-time) telemetry was made available to UCB for instrument health and safety monitoring. Another interface with MSOCC was to the GSFC Flight Dynamics Facility (FDF), the organization tasked with the requirement for orbit and attitude-related computational services for all GSFC's low earth orbiting satellites. For EUVE, their services included daily generation of TDRS and EUVE ephemerides, EP high gain antenna gimbal pointing angles, and User Antenna Views (UAVs) which aided the FOT in the generation of TDRSS service requests. FDF also provided less frequent support in the area of sensor (star tracker, gyro, sun sensor) recalibration and trending, and on-board-computer (OBC) attitude verification. It is important to understand that the EUVE mission, timed as it was on the "trailing edge" of the legacy technology of the late 1970's and 1980's, was not designed with outsourcing in mind. The original EUVE ground system is a classic example of the institutionally provided services which were developed within GSFC to benefit from the economies of scale associated with centers of expertise in each functional area.

A final, key component of the ground system that was built at GSFC is the Software Development and Verification Facility (SDVF). This computer lab was created for the development and testing of flight software modifications. The SDVF houses a medium-to-high fidelity spacecraft simulator. Although collocated with resources used to support other NASA missions in a similar way, the EUVE SDVF equipment is largely dedicated to the EUVE mission. This characteristic thus distinguishes it from the other truly "institutional" (i.e.,"shared") resources already described.

UCB ESOC

The Center for EUVE Astrophysics, (CEA) a part of the UCB Space Sciences Laboratory was, and continues to be, responsible for the operation of the EUVE astronomical payload, which they also built. At launch, payload operations were conducted around-the-clock by operators and scientists who manned the EUVE Science Operations Center at Berkeley. In the post-launch period, much work was done to characterize and calibrate the various instruments and detectors onboard. After completion of the all-sky survey, weekly target lists called science plans were generated at UCB from NASA-approved sources chosen from successful EUVE Guest Observer proposals. These science plans were forwarded to the GSFC CMS and FDF computers whose output the FOT would then use to build daily spacecraft storedcommand loads and arrange for the necessary TDRSS communications support to conduct daily operations. Science and engineering data flowed in near real-time back to UCB. As required, ESOC operators forwarded Execute-on-Receipt (EOR) payload command packets to the GSFC FOT who uplinked these to the spacecraft.

Over the course of the mission, the robust performance of the payload telescopes and electronics became well established. UCB therefore proposed to downsize from three shifts to one as a cost savings venture. This had also been proposed in 1994 by a GSFC study[3] (known hereafter as the Polidan Study) commissioned by HQ to suggest ways to cut EUVE operations costs. (The NASA budget to conduct spacecraft operations was generally in decline, and more so for a mission like EUVE nearing the end of its primary science phase). To mitigate the risk involved to the payload's health and safety, plans were made to develop a monitoring program which would page operators in the event of any payload anomaly. UCB selected RTworks, a commercial expert system software package from Talarian Corporation, to automate the payload monitoring. A suite of UNIX-based software was then developed by UCB to interface RTworks with the EUVE telemetry stream. Payload operations personnel developed and implemented into RTworks a set of rules that the software uses to review incoming payload telemetry. In the case of an anomaly, UNIX-based scripts notify an on-call operator via pager. The operator, after reporting to the ESOC, then evaluates the problem and takes corrective action (e.g., emergency commanding) as necessary. The automated system itself does not command the payload in response to a problem; the decision to restrict payload commanding to a human operator greatly simplified the development of the system. With the successful implementation of this technology in early 1995, UCB further reduced to "zero shift" operations in January 1996 by programming the RTworks system to conduct all routine console monitoring, thus freeing CEA personnel to perform other tasks. UCB has done a commendable job in implementing their system, and their work has broad application in future science operations centers. They have also done a good job documenting their experiences and lessons-learned on this significant undertaking.[4,5]

Cost Reduction Measures at GSFC

Meanwhile, budgetary pressures at GSFC mandated a reduction in the size of the FOT and the legacy ground system. As part of GSFC's Continuous Process Improvement (CPI) goals, several simultaneous activities were undertaken that were key to making the eventual outsourcing feasible. The first was the migration of the EUVE CMS code from the institutional IBM mainframe onto a mission-unique DEC MicroVAX. This was accomplished between mid-1995 and the end of 1996.

Second was the decision to rehost the MSOCC EUVE and CGRO code to the GSFC Transportable Payload Operations Control Center (TPOCC) ground system, reducing the number of aging Perkin-Elmer systems (and their operators) needed within MSOCC. The TPOCC system, in contrast to MSOCC, is implemented as a distributed architecture, workstation-based design. The decommutating front-end device and the display workstations can all be easily housed within a small room. Missions controlled from GSFC launched from late 1992 until recently have primarily used this ground system design. Examples are the Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX), the Rossi X-Ray Timing Explorer (RXTE), and the Solar and Heliospheric Observatory (SOHO).

APOCC

As part of a larger Flight Testbed for Innovative Mission Operations Program (FTB-IMO), in which the EUVE Project solicited and conducted innovative operations-oriented experiments using the spacecraft and ground system, a proposal was adopted from the Flight Operations contractor, Loral Aerosys (now LM). It called for the reduction in size of the FOT concurrent with the design and implementation of an Automated Project Operations Control Center (APOCC)[6]. The APOCC would, similar to the UCB RTworks system, monitor telemetry on unmanned shifts and page the FOT in the event of a spacecraft bus anomaly. Unlike the ESOC system, however, APOCC was proposed to actually command the spacecraft for routine operations, and initiate reacquisition sequences through the Space Network in the event of a late or negative acquisition of signal. Due to its basic design, APOCC could also be used on other TPOCC-based missions like CGRO and RXTE. With this in mind, the EUVE Project approved the development of APOCC on a schedule that would have reduced the FOT to a one-shift operation (8-10 Full Time Equivalents, (FTEs) down from a launch size of 23) by October 1996. This would have enabled around-the-clock EUVE science operations to continue (with APOCC on the off-shifts) for the duration of the then-budgeted mission (through FY 1997).

THE CALL TO OUTSOURCE

In March 1996, UCB submitted to NASA an unsolicited proposal calling for an "EUVE Outsourced Extended Mission" (OEM)[7]. The proposal was birthed in response to a growing interest at NASA HQ in the concept of outsourced satellite operations to academia (part of the Agency's new strategic goals) and by a recommendation of the Polidan Study that possible cost savings could be achieved by the transfer spacecraft operations management and control from GSFC to UCB.

GSFC Considerations

The EUVE Project was asked to evaluate the proposal and make a recommendation to HQ. This GSFC group consisted of the EUVE Associate Project Scientist, the Mission Director, the FTB-IMO Technology Manager, a computer and data archivist expert who represented the EUVE Project Manager, and a previous Project Operations Director. The group was disinclined to the UCB OEM proposal for various reasons:

1. The proposed cost for the outsourced mission would exceed that of the baselined TPOCC/APOCC design.

2. The TPOCC system had not yet been delivered and validated by the LM FOT so that there was as yet no viable, transportable system to provide to UCB as government furnished equipment (GFE) with which to control the spacecraft. Procurement of a commercial ground system was judged to be disadvantageous in light of the money already spent on the MSOCC-to-TPOCC conversion, the additional cost, and the additional associated technical risk.

3. The outsourcing would jeopardize completion of the APOCC system, which was viewed as cutting edge control center technology which had specific application in other GSFC control centers. Considerable work on this system had already been accomplished.

4. A sole-source extension of the EP flight operations contract had been awarded to LM eight months earlier and the specter of a legal challenge presented itself.

5. Many technical details of the UCB unsolicited proposal were to be supplied by an as-yet-unselected "industrial partner", therefore it was not possible to assess the feasibility of most key parts of the plan, both technical and fiscal.

6. The schedule proposed to accomplish the outsourcing was not viewed as realistic. The industrial partner was to establish a new S/C control center and ground system, reproduce and supply the institutional services of GSFC's FDF and SDPF facilities, take over all ground software maintenance responsibilities, and conduct S/C operations; all within a six month period.

The Decision

In April 1996, noting the EUVE Project's concerns, NASA Headquarters made a policy decision that accepted the OEM proposal in principle, but required significant changes in the UCB plan and closer consultation with GSFC on how to outsource the mission. The EUVE Program Scientist at HQ issued a communication[8] to GSFC and UCB in which he outlined four "Prime Objectives" that were designed to maximize the outsourcing benefits to NASA and to the public:

1. A university model — "EUVE mission operations should transition to a location at or near the UCB campus, to enable student participation and to approximate the likely setting for future university-run mission operations models."

2. An education focus — "After transition of mission technical and operations knowledge, and establishment of a robust core operations capability, an education component should be attached to EUVE mission operations in order to foster science and engineering training and outreach."

3. Technology dissemination — "Technology innovation, testbedding, and dissemination shall continue to be an important objective for the EUVE program. The focal point at NASA/GSFC will be [the FTB-IMO Technology Manager] , who will keep the UCB team informed of technology advancements within NASA, and will assist in disseminating technical and operations developments generated within the EUVE team."

4. University responsibility — "After successful completion of the transition, both sides agree that leadership of and responsibility for the continued operation of EUVE shall transfer from NASA to UCB."

MAKING IT HAPPEN

The GSFC EUVE Project began regular meetings in earnest to address the various technical, programmatic, legal and schedule problems which presented themselves.

Procurement and Legal Challenges

In June 1995, the GSFC Project presented a case to the Center's procurement officials for a sole-source extension to the EP Flight Operations Team contract which was due to expire in July 1995. This having been accepted and established, there was concern that a legal challenge might come from the LM incumbent if the government initiated an agreement with UCB for operation of the satellite. In fact, the government was actually on the verge of exercising a single 14.5 month contract option since the one-year basic term (July 1995 to July 1996) was nearly complete. After many long discussions with GSFC legal counsel and HQ, it was decided that through the use of a Cooperative Agreement (CA), based upon the acceptance of UCB's unsolicited OEM proposal, an outsourcing activity could proceed. This had several complications. The technical details of UCB's proposal were to be supplied by an industrial partner which UCB had not yet selected. UCB had gone forth with a Request for Proposal (RFP) in early April 1996 and were requiring bidders' proposals by the end of May. They anticipated making a selection by mid-June. In the use of a Cooperative Agreement, however, the government asserts its intent to be "substantially involved" with the recipient when carrying out the activity, (but must also refrain from mandating requirements on the recipient). Since the government could not be involved in a university procurement activity, it was clear that GSFC would have to wait for the result of UCB's procurement before proceeding with a CA. An interesting complication was that unless they were going to protest the whole activity, the LM incumbent was judged as likely as anyone else to bid.

The Procurement Plot Thickens

The May 31 deadline came and went without anyone responding to the RFP. Although the government was not in a position to ascertain the reasons, LM suggested (informally) that for them the technical difficulty of the tasks involved on the schedule to accomplish them, and the fixed price nature of the contract envisioned by the RFP (meant by UCB as a means to control costs) made it too risky a business venture. UCB urged strongly that GSFC should sign a CA with them, and let them put LM under contract by mid-July since their unsolicited OEM proposal held the following contingency clause: "In the event that all bids received are rejected CEA will exercise its back-up plan to take over platform operations independently of an IP [Industrial Partner]". This argument was deemed insufficient by the Project, and negotiations were undertaken with LM to rework the single 14.5 month option and break it into three smaller pieces- 6 months, 4 months, and 4.5 months. Eventually the 6 month piece would be expanded to 8 months, with the cooperation of LM, so that the handover could occur at the earliest feasible time.

Meanwhile, as anticipated, a technical blow was suffered by the APOCC development task. In the OEM, UCB proposed augmenting its RTworks payload monitoring system to monitor the spacecraft bus. Thus, they had only a limited interest in the LM APOCC development activities which were funded under the government's FOT contract with LM. Therefore, should GSFC have entered into a CA with UCB, and not elected to exercise the 14.5 month option on the FOT contract, UCB would most likely have contracted LM for continued spacecraft operations, but with no provision for ongoing APOCC development work and expense. This period of procurement confusion from April through June, 1996 resulted in the loss of most of the APOCC task key personnel, who took other positions within LM. They simply could not know whether there was going to be programmatic commitment for the completion of their work.

Much legal wrangling also continued over the nature of the CA. According to HQ policy, the primary purpose of the CA must be to "transfer something of value" or "to carry out a public purpose of support or stimulation as authorized by Federal statute". Although an outline of the public purpose was provided in the communi-cation from HQ on the direction to proceed, it was also evident that UCB could not execute this public purpose until such time as they had a functioning control center capable of conducting EUVE spacecraft operations. GSFC legal counsel and procurement officials therefore suggested that the CA be drafted in two phases. The final CA language was written thus:

"During Phase 1, GSFC will have responsibility for project management, mission operations and project science functions; UCB will have direct responsibility for payload operations, data processing, science support services, science investigations, Explorer Platform Operations Center (EPOC) development, operations and data related to technology investigations, and educational and community outreach initiatives. During Phase 2, GSFC will relinquish control of remaining EUVE functions to UCB; UCB will have direct responsibility for all EUVE activities. Phase 2 will begin when UCB has demonstrated to GSFC's satisfaction its ability to safely and reliably command and control the Explorer Platform."

With this wording, the statements of work in both GSFC contracts with UCB at that time were adequately covered and replaced by the Cooperative Agreement (and funding could proceed on that basis). However, the full exercise of the public purpose would not occur until the commencement of Phase 2.

Programmatic Challenges

In any new activity there are many policy questions and Project-level issues that arise. Briefly summarized, the following are some of the key programmatic challenges faced:

1. Lack of an appropriate organizational structure at GSFC to facilitate the outsourcing. The EUVE Project Manager (now retired), who was actually the GSFC Orbiting Satellites Project Manager in the Space Sciences Directorate, was responsible at the time for the management of nine currently orbiting scientific satellites. He felt that he lacked the resources to undertake the large development effort required for the outsourcing. A different Directorate (Mission Operations and Data Systems) was actually responsible for implementing and operating the EUVE ground system itself. This complicated the interface to UCB, the decision-making process at GSFC, and the interface to GSFC upper management. Additionally, key GSFC EUVE Project and institutional support personnel had other non-outsourcing responsibilities. UCB felt the lack of a completely dedicated team slowed their progress. This led to conflicting perceptions on the time necessary to accomplish various action items, and at some level, the amount of time necessary to accomplish the outsourcing itself. Eventually a Senior Manager from the Center Director's office was assigned to ensure that things progressed smoothly. As a final note, GSFC was in the midst of laying the groundwork for a centerwide reorganization, happening first within the Mission Operations and Data Systems Directorate. Simply stated, the outsourcing was not an activity that benefited from prior planning at GSFC, and proceeded from the bottom up, not the top down.

2. Establishment of appropriate programmatic controls and milestones. Because of the use of a Cooperative Agreement, the government, though "substantially involved", was prohibited from placing requirements on UCB. Though strong in their commitment to accomplish the activity, and staffed with many capable people, the UCB lack of experience in the areas of satellite control center development and flight operations was evident at GSFC. To understand the details of the "back-up plan" mentioned, but not described in the UCB OEM proposal, GSFC called for a preliminary design review of the plan by a team of experienced ground system development managers at GSFC. This was held on June 27, 1996. The assessment of the reviewers was that though the meeting was a productive working group, UCB was a couple months away from a viable preliminary design. Progress on the design and other operational issues was accomplished through weekly telecons and many emails. A second review of the Berkeley plan by the same reviewers occurred in early December 1996. The overall approach and design had matured to the satisfaction of all present. UCB recommended the inauguration of a "punch list" of key outsourcing activities and a "success criteria checklist" that could both be periodically reviewed by senior managers on both coasts to track progress. This proved to be an effective approach, as the lists were diligently updated by UCB, and three such telecons were held from January to March, 1997. At the handover telecon held on March 14th, a Memorandum of Agreement was signed (by fax) by the principals attesting to the readiness of the UCB team to control the spacecraft, and documenting the overall sound condition of the GFE'd systems. The enhancements and additional systems which the government agreed to provide after the handover were also noted.

3. Establishing safeguards for the success of the transition. It became very clear as the technical details were better understood that the UCB FOT would not have the luxury of extensive training in EUVE operations. To guard against the consequences of an untimely spacecraft anomaly, GSFC thought it prudent to encourage and foster the establishment of a "safety net" contract between UCB and LM for the post-handover period. This was agreed to by all parties and reached in a fairly uneventful manner. Harder was establishing the nature of the ongoing relationship that would exist between UCB and the various pieces of GSFC institutional support which would not be outsourced. The generation of Memoranda of Agreement between these groups and UCB has been somewhat laborious because of the lack of precedents for this kind of (outsourcing) activity. Frequently asked questions included the following:

How will the cost of GSFC support be paid?

Who is responsible for maintenance of GFE?

Are there parts which get funded out of “institutional” resources?

Who pays for any contractor or civil servant travel to Berkeley in support of the outsourcing?

What mechanism will be established with the CA for the funding of all those involved?

Additionally, programmatic decisions were required in the establishment of the “Success Criteria Checklist”. Should UCB be required to demonstrate an on-orbit recovery from safepoint and/or safehold modes? Should UCB exercise the Deep Space Network contingency direct-to-ground communications path before the handover? How long should GSFC provide “shadow” operations from the east coast? Should the UCB FOT be required to pass the same certification test that the GSFC FOT requires?

Other questions that needed answers were: does the government have the authority within a cooperative agreement to dictate a schedule? How much training is necessary? How many end-to-end tests are sufficient to demonstrate overall system reliability? When do you allow commanding by the new control center to the actual spacecraft? Questions of this kind seemed to arise daily. They were almost always related to the amount of risk willing to be taken.

4. Managing the changed relationship with the astronomical community. The EUVE Project Scientist was responsible from the earliest days of the mission for acting in a nonpartisan manner to ensure that NASA and community science objectives were met. In the outsourcing, this role was passed to the UCB EUVE Observatory Director. The prospect of giving UCB the authority to resolve disputes on issues of data rights or observing schedules raised legitimate concerns within the EUVE Users Committee, a Project-chartered group of EUVE users representing various organizations. This was a potential conflict of interest since scientists at UCB were among the more frequent users of the spacecraft. This concern was solved by the establish-ment of a structure that includes a NASA Science Advisory Board which has top level responsibility for ensuring the equitable and appropriate operation of the observatory. Additionally however, the annual call for GO proposals was delayed due to uncertainty in the outsourcing schedule.

5. Managing the work and the morale. In the statement of work for the final LM FOT contract option, LM was given a very challenging set of assignments by the EUVE Project. They were to continue flying the spacecraft safely, validate the new TPOCC ground system for operation with the satellite, attend to any FTB-IMO experiments that arose, finish the development and integration of an APOCC prototype (now more for the benefit of other GSFC missions than EUVE) and train the incoming UCB FOT to do their jobs. They were to do this (because of budget) without additional members. In fact, they were to transition to a single shift operation and downsize the team to a level about one half of the size at launch before relinquishing control to UCB. The Project chose a cost-plus-incentive-fee structure for the contract with both cost and technical incentives that would increase fee if met. This provided some motivation for LM to accomplish these tasks. Meanwhile every effort was made by the government to focus on the collective technical challenge, and to promote cooperation between LM and UCB. In truth, much of the credit for keeping LM engaged in the process was due to the skill of their FOT Program Manager. The cooperative spirit of the UCB Operations Manager and the fortunate timing of the availability of flight operations jobs on the GSFC Earth Observing System (EOS) program, also greatly aided in this effort.

Technical Challenges

There were truly many technical challenges to be overcome to successfully accomplish this activity. The foremost among these was to maintain spacecraft operations so that there would be no interruption to science while accomplishing the transition between operations centers and Flight Operations Teams. The most significant technical difficulties encountered will be individually described in this section. First however, a summary of the overall technical approach is provided.

The Approach

The technical steps taken to achieve the handover can be retraced at a high level in the following sequence:

1. UCB secured an FOT and sent them to GSFC for MSOCC-based training on the S/C, and to participate

in the TPOCC training being provided to LM by members of the TPOCC development and acceptance testing teams.

2. Whatever GFE that could be made available was sent to UCB immediately for their familiarization and the establishment of the Berkeley “EPOC” control center. Two main shipments of GFE occurred, one in mid- October, and one in mid-January. Each drop contained a TPOCC front-end device, workstations, X-terminals and miscellaneous peripherals. In each case, GSFC hardware, software and network personnel traveled to Berkeley to facilitate the installation. Three CMS systems were also passed in phases to UCB. A GSFC development system in October; one of the two GSFC operational systems in January, and the other after the March 14, 1997 handover date.

3. The GSFC FOT validated the new TPOCC system for operational use with the spacecraft by testing it in parallel with the legacy MSOCC system. Testing occurred with both the EUVE simulator and the spacecraft. UCB FOT members also heavily participated in the operational debugging of the TPOCC system both from GSFC and the UCB EPOC.

4. As trained operators were able to return to UCB, tests of the developing EPOC system and UCB’s operational procedures were conducted with the EUVE simulator at GSFC. Eventually the capability of the UCB system was demonstrated sufficiently that occasional spacecraft passes were taken from the west coast with the GSFC FOT shadowing on the east coast. By mid-December, the UCB FOT was controlling the spacecraft three days of the week and working with the simulator between passes and on the remaining days.

5. Operational transfer of satellite control to UCB occurred in two distinct phases. First, the “off-line” tasks were handed over, and then the “on-line” activities. The off-line functions include science plan processing and command load generation using the CMS system, and TDRSS request generation through the UPS system. The on-line activities are prepass ground system setup, S/C telemetry monitoring, command uplink and postpass data archiving. Prior to each handover, a Project Review Telecon was scheduled as a “go/ no go” gate for the transition. Off-line functions were transitioned on January 3, 1997; the handover of complete operations to UCB for a sustained shadow mode period began on February 3rd, and continued to the formal March 14th cutover date.

6. It was decided that no attempt would be made to relocate the EUVE simulator or outsource the flight software maintenance function. The expertise needed for this enterprise simply could not be replicated at UCB for any reasonable cost. UCB did make a concerted effort to duplicate the SDPF and FDF functions before the handover. These efforts labored however, and were eventually identified as non-critical path items. UCB dropped its plans to outsource the FDF functions, and rescheduled its replacement of the SDPF until after the cutover date. Additional details on this are provided in item [6] of the next section.

Specific Difficulties

There were many difficulties encountered throughout the period. In retrospect, the number of significant problems overcome in such a short period of time by such a small overall team is no less than remarkable.

1. Though an obvious one, there was the daily difficulty of the three hour time difference between UCB and GSFC. This affected everything from telecon times to the building of appropriately time-tagged computer products during parallel operations.

2. The original operational release date of TPOCC was January 1996. Because of various programmatic difficulties, this date continued to slip so that in mid-1996, when UCB was solidifying their “backup plan” for the Berkeley ground system, there were many within UCB that felt another ground system would be preferable. These concerns gave way to the financial reality that the GSFC TPOCC system would be provided free as GFE to UCB whereas any other Commercial-Off-the-Shelf (COTS) system would not. There was also significant concern about the validation of the command functionality of a new system- an issue which would take time and inject risk into the activity.

The EUVE TPOCC system design called for two custom-built front-end devices which were connected by ethernet LAN to several HP workstations, X-terminals and other peripherals to comprise two operational strings. UCB was eager to be provided a front-end at the earliest possible date. This was difficult because one was being used by the GSFC TPOCC development team and the other was located in the EUVE MOR for LM use in training and validation with S/C telemetry. Eventually, use of a planned CGRO front-end allowed the development string to be shipped to UCB. The TPOCC software releases were timed to permit adequate training and testing on both coasts. The large job of translating the entire set of routine and contingency operations procedures (procs) from MSOCC to TPOCC fell to the LM FOT. The GSFC FOT also kept a master checklist, reviewed weekly by the NASA Mission Director, of TPOCC capabilities which were demonstrated by testing. The testing was accomplished both with the EUVE simulator and, where appropriately benign, with the spacecraft.

As trying as the logistical problems of TPOCC shipment and configuration were, it was the actual system software problems which threatened the schedule of the planned handover. Weekly discrepancy report (DR) meetings were held to review the critical, urgent and routine problems cataloged. Through much hard work, all the critical problems were worked out of the system by mid-March. The small development and testing team has had to constantly reprioritize the competing needs of the EUVE and CGRO missions. Although required to work simultaneously on both, an agreement was reached with the CGRO Project at GSFC in December 1996 to permit the concentration of resources on EUVE until a full-featured release was delivered. Now that this has been accomplished, the emphasis has been redirected to the CGRO mission and this has somewhat protracted the completion of the EUVE cleanup release. Part one of a two-part, GSFC-funded, post-handover release was provided to UCB in July 1997. The final delivery is scheduled for September 1997.

3. During the critical period from mid-November to mid-December, the usually reliable EUVE simulator developed several significant problems. Although every effort was made to solve these problems, the combination of their intermittent nature and the one-of-a-kind hardware lash-up in the SDVF prevented a quick fix. As a result, driven by a need to keep schedule, additional risk was taken through the limited testing of systems and procedures with the spacecraft in place of the simulator. The schedule pressure felt by all to validate these procedures led (unfortunately) to a LM operator error in December, causing the only operator-induced entry into safehold mode of the mission.

4. Chief among the reengineering activities necessary for the success of the outsourcing was the establishment of new data circuits between GSFC and UCB. These would not only be used for eventual operations from the west coast, but parallel operations with GSFC during the shadow period, and special testing with the simulator as well. Communications experts within the GSFC NASCOM organization were called upon to engineer and coordinate these changes. Early on, one of the key difficulties of the developing UCB EPOC was its ability to repeatably send good command blocks. After a week of troubleshooting by TPOCC and NASCOM personnel, the problem was traced to the use of a standard internal TPOCC clock source for the command timing signal, rather than a carrier-provided external clock. Although at GSFC, the internal clock source works flawlessly, timing problems caused by the long line extension to Berkeley forced the use of the carrier-provided clock to maintain synchronization. Another source of line difficulties arose with the NASCOM-provided Programmable Telemetry Processor (PTP) which was placed at GSFC on the inbound command circuit from UCB to effect a translation from the NASA 4800 bit block format to Internet Protocol. UCB was one of the earliest users of the PTP in this application as part of NASCOM's ongoing migration away from the old 4800 bit block format. The problems on UCB's command circuit led to the recognition of a design flaw in the PTP. Whereas this was good for NASCOM, it produced much consternation and retesting for UCB until the problem was identified.

5. Spacecraft engineering data trend analysis at GSFC on the legacy system was done by a LM-developed system known as the Engineering Analysis System (EAS). In GSFC TPOCC-based control centers, a system called the Generic Trend Analysis System (GTAS) is used. A GTAS system which was installed in the EUVE MOR was tested and validated by the LM FOT during the months prior to the handover for its suitability to conduct trending for the mission. The UCB FOT was also trained at GSFC in its use. Unfortunately, the GTAS system which was shipped and set up at Berkeley seemed to have no end of problems. These were eventually diagnosed to be due to a combination of hardware problems, user configuration, and elusive TPOCC/GTAS interface problems.

Although every reasonable effort was made by personnel from both coasts to solve the problems, the GTAS system was not functioning at its full capability by the handover date. Once the handover occurred, GSFC made the legacy EAS system available for UCB's use. The timeline for the outsourcing simply did not have enough slack to account for technical difficulties that did not have quick fixes; as a result, more risk was accepted.

6. In mid-December 1996, shortly after the second ground system review by GSFC, UCB gave up its plan to outsource the institutional services provided by the

GSFC Flight Dynamics Facility. UCB had in this case underestimated the task. There was simply too much development work to be done and too much testing involved to squeeze it all in by mid-March. UCB was constrained by the amount of money available for this effort, and also suffered the loss of a key programmer in the fall of 1996. UCB proposed to use FDF-provided services for the foreseeable future. It may be that CPI work in the FDF, moving legacy software to workstation-based platforms, could enable a later migration of these functions to UCB. The outsourcing of the GSFC SDPF functions meanwhile, was targeted by UCB for early June 1997, but now seems more likely to be completed by September, 1997.

LESSONS LEARNED

There are many lessons, in many areas, that can be drawn from the outsourcing of EUVE. They can be categorized many different ways. The categories presented here are operational, programmatic, procurement & contractual, and technical.

Operational:

With the collocation of the spacecraft control center and science operations center now at UCB, various operational efficiencies have been enabled and UCB has done a good job taking advantage of them. These have already been detailed at length[9] but can be summarized briefly here as follows:

- Reduced the FOT staffing level to 8 FTE whose responsibilities also include payload operations.

- Reduced the human effort required in the spacecraft planning and scheduling process by ~75%, from 2.0 to 0.5 FTE.

- Reduced the observation planning cycle by 33% (from 35 to 23 days). This was also enabled in part by CPI efforts undertaken in the GSFC TDRSS Network Control Center (NCC) as well coordination between the NCC and UCB.

- Reduced the response time for Targets of Opportunity (TOOs) by a factor of two for the best-demonstrated effort (~4 to ~2 hours).

These benefits had already been recognized, if not quantified, by GSFC before the EUVE outsourcing and formed the basis for the collocation of the RXTE and MIDEX spacecraft and science operations centers.

Programmatic:

The following issues, principles, and recommendations have been elaborated at length in this paper:

- Strong Project Management is required to conduct an orderly, minimal-risk activity. This should include the identification at the beginning of the process of a senior level manager with ultimate decision-making authority.

- Strong commitment and support from the outsourcing center is necessary to keep schedule in light of the inevitable technical challenges. Without the "deep bench" of technical help available at GSFC, especially in the areas of control center development and data circuit engineering, the EUVE outsourcing would not have happened as it did. Count on considerable reengineering hours being spent by members of your staff. Make sure appropriate time is allocated and priority given to the work.

- Up-front establishment of the goals of the outsourcing will provide clarity and motivation to those involved.

- Assess the impact of the outsourcing on any other process improvement activities within the Project. The EUVE APOCC prototype, although brought to completion by the extraordinary effort of those at GSFC, was very nearly extinguished by the out-sourcing.

- Think through the means to maintain morale. Assess the overall schedule for realism and the availability of jobs for any displaced operations personnel.

- Assess the impact of the outsourcing on the science community and seek to obtain their support.

- Emphasize the need for strong and constant communication. The importance of weekly telecons, and daily emails and/or phone calls cannot be overemphasized.

Procurement and Contractual:

- Carefully assess whether the procurement basis of the outsourcing must proceed as a contract, grant or cooperative agreement. It may be, as in this case, that a phased approach will be necessary. Flexibility and creativity are necessary throughout the process.

- Be aware of the need to provide incentives to the incumbent FOT if a transition to a new team is involved.

- Keep legal and procurement officials intimately involved in order to reduce the possibility of protests or other policy problems.

Technical:

- Seek to outsource missions whose ground systems are already well validated, modular, and stable. Plan for local experts to travel to the outsourced site to aid in its establishment.

- Conduct at least one thorough design review of the new control center to achieve technical consensus and focus.

- Consider a phased (off-line, on-line) approach to the transfer of operations. Again, be creative and flexible.

- Recognize the importance of the spacecraft simulator in the outsourcing timeline.

- Allow hands-on control of the spacecraft by the new FOT as early as possible.

- Allow testing of the new ground system with the actual spacecraft as early as prudently possible.

- If time permits, exercise at least some subset of contingency recovery procedures from the new control center by the new FOT before the end of the shadow operations period with the old control center.

- Recognize that although beneficial as an educational resource, satellite operations done at a university setting must be accomplished by a core of dedicated salaried professionals; not just students.

CONCLUSION

There were enormous challenges, some technical, some political, and some ideological, when the EUVE outsourced extended mission was first conceived. The winning performance delivered by the combined GSFC/UCB/LM team showed that even a first-ever effort like the EUVE outsourcing can be completed on a tight budget, on schedule, and with only moderate risk, but with much hard work. However, it should be noted that any mission contemplating outsourcing should think through the procurement and programmatic processes (e.g., proposals, cooperative and post-outsourcing agreements, project reviews, etc.) well in advance; the EUVE experience suggests that such up-front planning will greatly help to smooth the overall outsourcing transition. The EUVE mission is now expected to run to at least 1999. The public purpose is also being served through the provision of unique educational benefits to a university environment, and the continued dissemination of technical, scientific, and operations developments generated within the EUVE program to society at large.

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